

BEFORE THE
Federal Communications Commission
WASHINGTON, D.C.

RECEIVED

FEB 27 2002

FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

In the Matter of

Revision of the Commission's
Rules to Ensure Compatibility
with Enhanced 911 Emergency
Calling Systems

)
)
)
)

CC Docket No. 94-102 /

**REPORT ON GSM CAPABILITIES
SUBMITTED BY TRUEPOSITION, INC.**

TruePosition, Inc. is filing this report to keep the record of this important proceeding current.

TruePosition has recently completed a comprehensive examination of its TDOA-based wireless location system in a GSM environment. This review demonstrates that TruePosition's solution for GSM carriers meets or exceeds the FCC's E911 Phase II accuracy requirements today. This is an important development because it dispels lingering uncertainty about whether subscribers using GSM technology can be located within acceptable accuracy prescribed by the Commission's rules.

No. of Copies rec'd
Lcl A B C D E

042

In 2000, the Commission waived the Phase II accuracy requirements for GSM providers predicated on the assumption that no compliant technology existed.¹ A lack of available alternatives necessitated the temporary acquiescence to GSM ALI accuracy shortcomings. The Commission premised its initial Phase II waiver for GSM systems on evidence that “the development of ALI capabilities for use by GSM carriers has lagged behind that for carriers using other interfaces,”² and that network location technology providers had not begun testing of GSM solutions.³ The Commission identified E-OTD as a technology (admittedly still developing) that presented the sole near-term option available to GSM carriers.⁴ The Commission recognized that E-OTD would not meet the accuracy requirements; however, it noted the possibility that E-OTD technology would improve, and made use of it contingent on improvement.⁵

Today, the Commission no longer finds itself presented with the choice of availability versus accuracy. A recent study establishes that TruePosition offers an alternative for GSM

¹ Revision of the Commission’s Rules To Ensure Compatibility with Enhanced 911 Emergency Calling Systems, CC Docket No. 94-102, *Fourth Memorandum Opinion and Order*, 15 FCC Rcd 17442 (2000).

² Id., ¶ 56.

³ Id.

⁴ Id. (“It appears that the NSS/E-OTD approach may be the only method available to GSM carriers for compliance with Phase II for some time.”).

⁵ Id. ¶ 68 (“To the extent that VoiceStream cannot comply with any of these conditions, it will be expected to use another ALI methodology that comports with our requirements. For example, if the E-OTD approach proves unable to provide 50 meter/67 percent accuracy within two years as projected, VoiceStream would be required to adopt another approach that would meet our accuracy requirements.”).

carriers that fully satisfies the Phase II accuracy requirements. A report describing the basis for this conclusion is attached as Exhibit A.⁶

The unqualified success of TruePosition's deployment of a network-based Wireless Location System ("WLS") for Cingular Wireless LLC ("Cingular") in Wilmington, Delaware, serves as an important foundation for concluding that TruePosition's technology will satisfy the FCC's Phase II requirements for all carriers, including GSM carriers.⁷ As part of the agreement between Cingular and TruePosition to deploy TruePosition's WLS on Cingular's TDMA/AMPS cell sites, Cingular and TruePosition tested TruePosition's WLS in an area covered by eighteen Cingular cell sites in Wilmington, Delaware. The test results show that TruePosition's WLS technology exceeded the Commission's Phase II accuracy standards by substantial margins. In 2,300 test calls, which included pedestrian, moving vehicle, stationary vehicle, and in-building test calls, the WLS produced locations accurate within 81.2 meters at the 67th percentile and 189.9 meters at the 95th percentile. The test calls were made using commercially available TDMA and AMPS hand-held mobile phones. The test samples and results were calculated pursuant to the requirements of the FCC's OET Bulletin No. 71.

Typically, the dominant source of location errors in most AMPS, TDMA and GSM environments is unresolved multi-path. TruePosition has developed sophisticated super-resolution techniques to help mitigate the effects of unresolved multi-path, based upon signal

⁶ TruePosition, Analysis of GSM Uplink Time Difference of Arrival (UL-TDOA), January 21, 2002.

⁷ TruePosition has also successfully tested its technology with Verizon Wireless over a CDMA network in Manhattan. This test showed that TruePosition's WLS will work in the most difficult RF environments anywhere. "Verizon Wireless and TruePosition Announce Successful Completion of Location System Test in Manhattan." December 19, 2000. http://www.trueposition.com/news_verizon.html.

bandwidth, coherent integration time, and signal-to-noise ratio. As Exhibit A notes, from the perspective of location accuracy, the significant difference between GSM and TDMA is signal bandwidth. There is a 5:1 difference in bandwidth that makes GSM significantly more immune to multi-path than TDMA. TruePosition's comprehensive analysis has demonstrated a 2:1 ratio of TDMA to GSM errors for the typical multi-path case, and a nearly 4:1 ratio for severe cases.

Based on this analysis, TruePosition has determined that the RMS TDOA errors for GSM will be approximately half of those for TDMA. Stated differently, the accuracy of TruePosition's WLS for GSM should be at least twice that of TDMA. Thus, if GSM had been deployed in Wilmington, TruePosition's WLS would have been accurate to within 41 meters for 67 percent of all calls and to within 95 meters for 95 percent of all calls. As a result, TruePosition is confident that its GSM solution, which is available for deployment, exceeds the FCC's accuracy requirements. In addition, the TruePosition WLS should achieve the FCC's accuracy requirements in most GSM networks when Location Monitoring Units are deployed at only fifty percent of an area's cell sites.

In addition to delivering compliant accuracy, TruePosition's WLS further enhances public safety by computing a caller's location within five seconds while providing PSAPs with the ability to continuously refresh the caller's location. This capability dramatically increases the likelihood that calls are routed to the correct PSAP, something that reliance on Phase I technology for routing does not. The speed at which TruePosition's WLS calculates a caller's location is obviously important. Although the Commission's rules do not at present require

location calculations to be made within a specified period of time, the Commission has recognized the importance to public safety of rapid responses.⁸

The results of TruePosition's live testing and analysis of GSM location accuracy, should alleviate further concerns the Commission may have with respect to the accuracy of Phase II solutions for GSM carriers. In addition, because TruePosition's WLS can locate all callers without respect to the handsets they use, this solution immediately addresses the issue of legacy handsets.

Respectfully submitted,



Philip L. Verveer
David M. Don

Willkie Farr & Gallagher
1155 21st Street, N.W.
Suite 600
Washington, DC 20036

Attorneys for TruePosition, Inc.

February 27, 2002

⁸ See Revision of the Commission's Rules to Ensure Compatibility with Enhanced 911 Emergency Calling Systems, *Fourth Memorandum Opinion and Order*, 15 FCC Rcd. 17442, ¶ 26 (2000) ("Emergency calltakers now must devote critical time and resources to questioning wireless 911 callers to determine their location. Emergency response teams must often waste critical minutes - or longer - searching for those callers."); *Third Report and Order*, 14 FCC Rcd. 17388, ¶ 4 (1999) ("These 911 call location difficulties represent a significant public safety problem. Nearly 70 percent of auto accident fatalities occur within two hours after a crash and, according to a conservative estimate, 1,200 lives are lost each year because of delay in discovering accidents.").

EXHIBIT A



Analysis of GSM Uplink Time Difference Of Arrival (UL-TDOA)

January 21, 2002



Introduction

Over the past nine years TruePosition has developed comprehensive knowledge about the capabilities and performance of Time Difference of Arrival (TDOA)-based wireless location systems. This knowledge was developed through extensive research, analysis and field deployments. A comprehensive analysis of TruePosition's TDOA-based wireless location system in a GSM environment has been performed, and the expected performance is well understood.

This document provides an overview of this analysis and details the expected performance of the TruePosition Wireless Locations System (WLS) in a GSM environment. The goal is to provide insight into the theoretical aspects of the performance of the TruePosition WLS in a GSM environment, as well as to relate this theoretical performance to previously measured performance in a TDMA environment. The fundamental nature of this analysis should establish confidence in the expected performance of the TruePosition WLS in GSM networks.

Review of the Fundamental Drivers of Location Accuracy

The TruePosition WLS estimates the position of a mobile station by measuring the time-difference-of-arrival between the signal received at the serving cell site and the same transmission received at other surrounding cell sites. The error in these TDOA measurements, not including the effect of multi-path, is given by the Cramer-Rao bound:

$$TDOA_{rms} = \frac{\sqrt{12}}{2\pi B (2BT SNR_y)^{1/2}}$$

where B is the signal bandwidth, T is the coherent integration period, and SNR_y is the signal-to-noise ratio (SNR) of the remote signal. The location error that results is approximately:

$$Location_{rms} \approx TDOA_{rms} P^{1/2} N^{1/2} GDOP_c$$

where P is the number of diversity antennas, N is the number of sites (valid only for $N \geq 3$), and $GDOP_c$ is the geometric dilution of precision (GDOP) relative to that at the center of a circular N-station configuration. From this it is straightforward to see that location accuracy is a function of signal bandwidth, coherent integration time, SNR, number of receive antennas, number of receive sites, and the geometry of the receive sites.

In AMPS, TDMA and GSM environments the signal bandwidth is too small to resolve all multi-path components. The unresolved multi-path components result in additional error in

Analysis of GSM UL-TDOA

the TDOA measurements. The effective multi-path delay spread is given by the square root of:

$$\tau_{\text{effective-spread}}^2 = \sum_i \tau_i^2 |A_i|^2 \text{sinc}^2 x - \left(\sum_i \tau_i |A_i|^2 \text{sinc}^2 x \right)^2$$

where A_i is the voltage amplitude of the i^{th} multi-path component, $x = \pi B$, and B is the signal bandwidth.

The larger the signal bandwidth the more multi-path components can be resolved and the smaller the effective multi-path delay spread. This is illustrated more clearly for TDMA and GSM in the following section. In most AMPS, TDMA and GSM environments the error caused by unresolved multi-path components dominates location accuracy. TruePosition has developed sophisticated super-resolution techniques to help mitigate the effects of the unresolved multi-path. The performance of these techniques is dependent upon signal bandwidth, coherent integration time and SNR.

Comparison of GSM Versus TDMA

From a location accuracy perspective the significant difference between GSM and TDMA is signal bandwidth. Figure 1 shows the ideal cross correlation of the reference signal with one from a cooperating site. This was computed by convolving the transmit wave-shaping filter with itself for each of the air-interfaces. The wave-shaping filter for TDMA is a “35% excess bandwidth, root cosine filter” with a 3 dB bandwidth of 24.3 kHz (the symbol rate). The GMSK waveform used for GSM has an approximate bandwidth of 120 kHz.

This approximately 5:1 difference in bandwidth and the resulting time spread of the signals makes GSM significantly more immune to multi-path than TDMA. Because of this, any multi-path components more than a few μs from the main path (typically line-of-site) will not effect the TDOA measurement for GSM. However, as can be seen from the figure, multi-path components tens of μs from the main path will effect TDOA measurements for TDMA. These farther out multi-path components also cause greater errors in the TDMA measurement since the error introduced is proportional to the delay given constant relative amplitude.

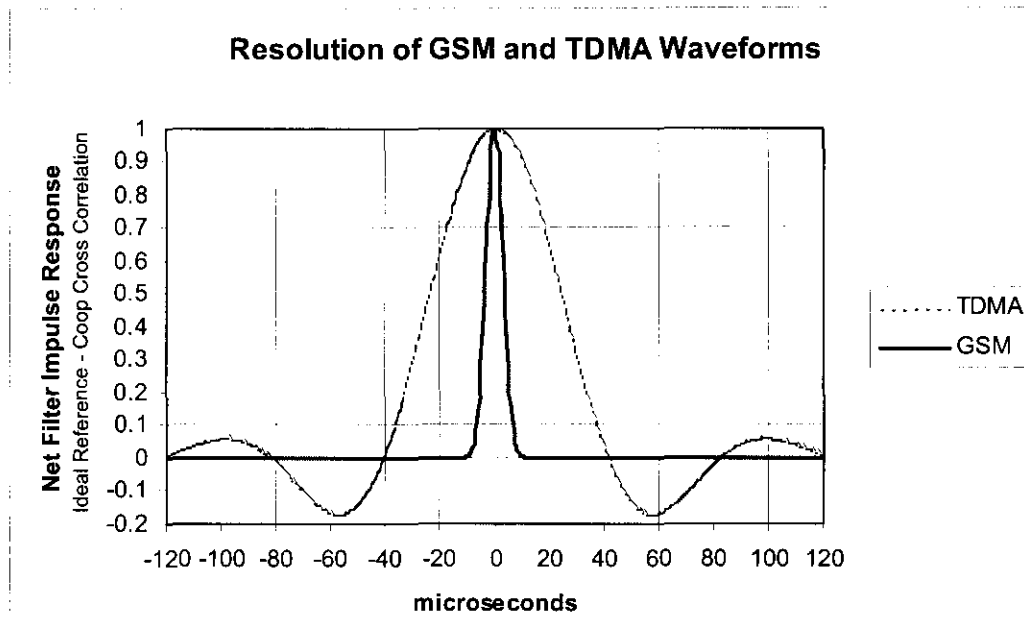


Figure 1 – Resolution of GSM and TDMA Waveforms

To illustrate the general effect of the smearing of multi-path components into the correlation peak of the main component, one can convolve a set of impulses with the relative amplitudes and delays representing the main path followed by a number of multi-path components. A simple model for the multi-path has components spaced at 2 μs intervals with amplitudes proportional to $\tau^{-\alpha}$ where τ is multi-path delay of each component and α is a constant. Larger values of α cause the more-delayed components to have smaller relative amplitudes. The overall multi-path spread is usually described as the RMS time spread of the power of all the multi-path components including the main component.

Figure 2 and Figure 3 show the effect of 10 multi-path components using a $\alpha=1.5$ which results in a multi-path spread of just over 1 μs . This might be considered a typical multi-path environment.

Analysis of GSM UL-TDOA

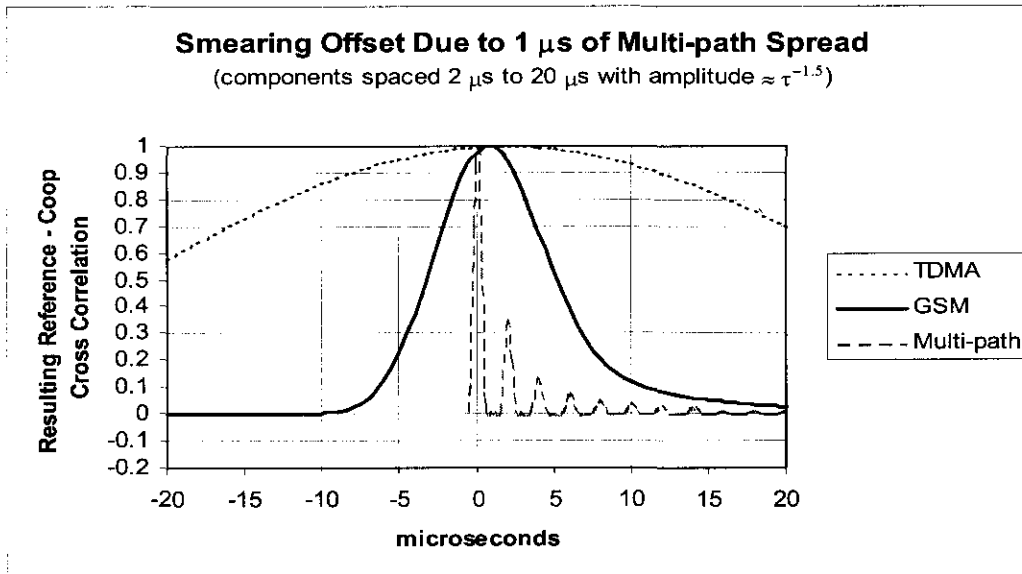


Figure 2 - The Effect of Typical Multi-path on TDOA Measurements

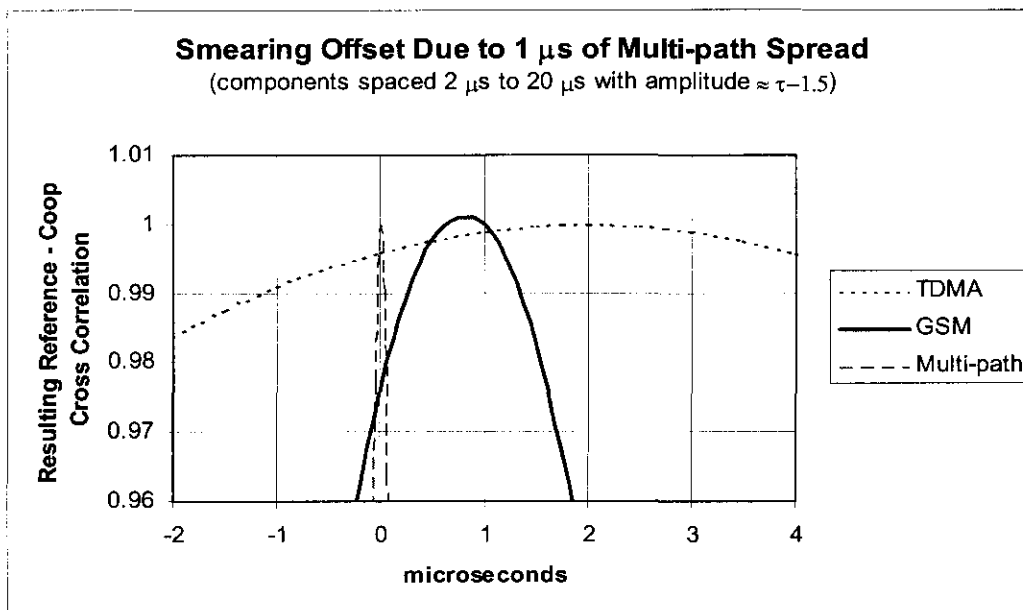


Figure 3 - The Effect of Typical Multi-Path on TDOA Measurements (Zoomed In)

Analysis of GSM UL-TDOA

As can be seen in Figure 3, the peak of the correlation for GSM is shifted by approximately 800 ns, while the peak for TDMA is shifted nearly 2000 ns (each ns is approximately one foot). The very broad peak of the TDMA correlation also makes it more sensitive to noise corruption.

Figure 4 and Figure 5 show the effect of 20 multi-path components using a $\alpha=1.0$ which results in a multi-path spread of 3 μs . This might be considered a severe multi-path environment.

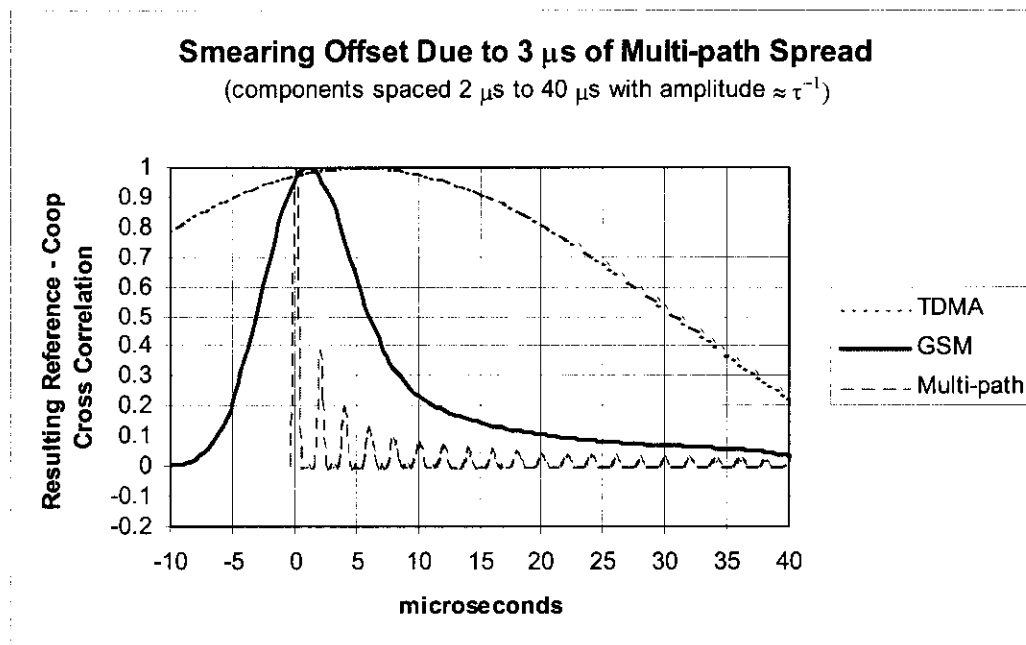


Figure 4 - The Effect of Severe Multi-Path on TDOA Measurements

Analysis of GSM UL-TDOA

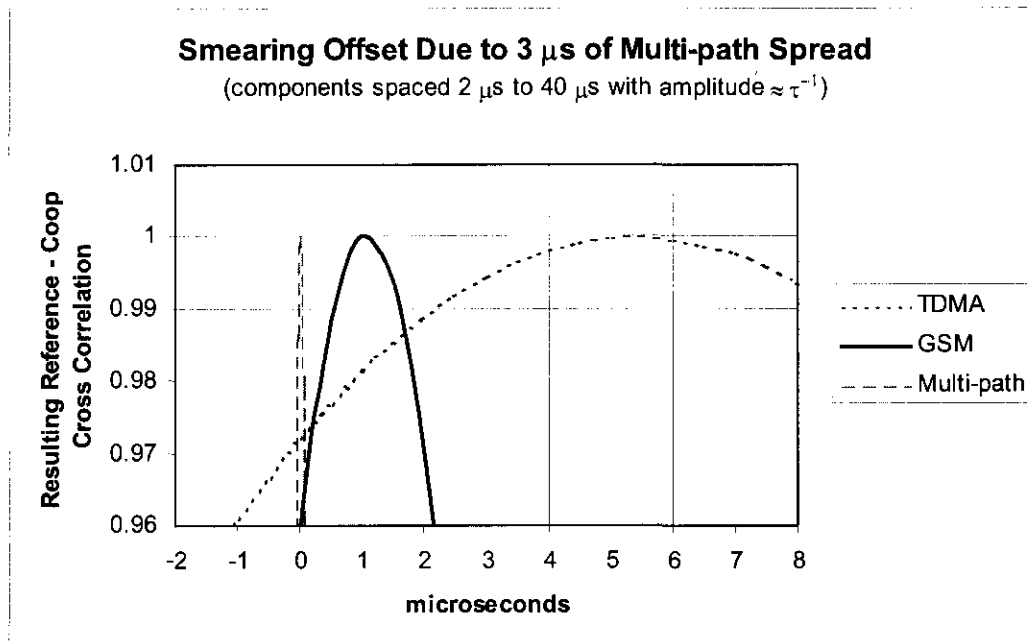


Figure 5 - The Effect of Severe Multi-path on TDOA Measurements (Zoomed In)

As can be seen in Figure 5, the peak of the correlation for GSM is shifted by approximately 1000 ns, while the peak for TDMA is shifted over 5000 ns. TruePosition utilizes super-resolution techniques to correct for large errors such as these in order to attain the location accuracy demonstrated in numerous deployments.

The above illustrations only show the general effect of multi-path since the phase of these components is not included. To verify that the differences shown by these simple illustrations will also be seen in real GSM deployments, a sophisticated simulation that utilizes the actual TruePosition location algorithms was modified to support the GSM signal bandwidth. Signals representative of both TDMA and GSM were generated and passed through a random multi-path simulation model. For each TDOA measurement this model generated independent Rayleigh distributed amplitudes and random phases for each of the multi-path components along with Gaussian noise added to the output. The results averaged over many TDOA measurements showed a 2:1 ratio of TDMA to GSM errors for the typical multi-path case shown in Figure 3, and nearly a 4:1 ratio for the severe case shown in Figure 5.

Coherent integration time and SNR also affect the accuracy of TDOA measurements. In a typical three-second data collection period the TruePosition LMUs collect 375 milliseconds of data from a GSM mobile transmitting at a power level of two watts, compared to one

Analysis of GSM UL-TDOA

second of data from a TDMA mobile transmitting at a power level of 0.6 watts. This means the integrated SNR for GSM and TDMA are effectively equivalent.

Based on this analysis of the effect of signal bandwidth, and the fact that integrated SNR for GSM and TDMA are effectively equivalent, TruePosition is confident that the RMS TDOA errors for GSM will be approximately half of those for TDMA. Given that in similar network deployments the number of receive antennas, number of receive sites, and the geometry of the receive sites will be the same, the accuracy for GSM should be at least twice that of TDMA.

To verify this conclusion an analysis was conducted to determine the expected performance of the TruePosition WLS in deployed networks. Both TDMA and GSM performance were modeled using TruePosition's predictive modeling tool. The 18-site Wilmington TDMA Trial network was used in order to establish a frame of reference with actual measured TDMA performance. In addition, the 172 sites covering the portion of Houston inside the Sam Houston Parkway were used to provide a more comprehensive test. Finally, an example 1900 MHz GSM network covering the same portion of Houston was used to provide insight into the effects of the different propagation environment, cell site density, antenna configurations, etc. GSM performance for both 100% and 50% LMU deployment densities were analyzed. Figure 6, Figure 10 and Figure 14 identify the network designs used for the three networks. In the 100% LMU deployment density cases LMUs were modeled at all sites. In the 50% LMU deployment density cases LMUs were modeled only at the sites displayed in green. Table 1 provides the overall results of the analysis.

Analysis of GSM UL-TDOA

| Network | Air Interface | LMU Deployment Density | 67% Performance (meters) | 95% Performance (meters) |
|---------------------------------------|---------------|------------------------------|--------------------------------|--------------------------------|
| <i>Wilmington (Trial Results)</i> | <i>TDMA</i> | <i>100%</i> | <i>81.2</i> | <i>189.9</i> |
| Wilmington | TDMA | 100% | 80 | 135 |
| Wilmington | GSM | 100% | 43 | 74 |
| Wilmington | GSM | 50% | 58 | 101 |
| Houston (850 MHz) | TDMA | 100% | 83 | 141 |
| Houston (850 MHz) | GSM | 100% | 44 | 75 |
| Houston (850 MHz) | GSM | 50% | 52 | 89 |
| Houston (1900 MHz) | GSM | 100% | 61 | 112 |
| Houston (1900 MHz) | GSM | 50% | 82 | 153 |

Table 1 - Predicted Location Accuracy Performance

Figure 7, Figure 8 and Figure 9 provide plots of the expected performance in the Wilmington network. Figure 11, Figure 12 and Figure 13 provide plots of the expected performance in the Houston 850 MHz network. Figure 15 and Figure 16 provide plots of the expected performance in the Houston 1900 MHz network. Each plot has a polygon that defines the region over which the 67% and 95% predictions were computed. The accuracy contours are only shown for this region inside the polygon. Cell sites without LMUs are shown by thin outlines of their antenna sectors. Even though no LMUs for sites outside the Sam Houston Parkway were included in the performance predictions shown in Figures 11 through 16, they are shown on the plots to put the deployed sites in context.



Analysis of GSM UL-TDOA

Although the predicted 67% performance is consistent with actual measured performance, the predicted 95% performance is slightly better than the actual measured performance. This is due to the fact that the predictive model tends to underestimate the effect of some outlier cases caused by third order anomalies (e.g. cell sites temporarily off line, interference, etc.). This is not a problem since the measured 95% performance is well within the FCC's specifications.

This analysis verifies the location accuracy of the TruePosition WLS in a GSM environment is approximately twice that of TDMA. In addition, the TruePosition WLS should be able to achieve the FCC's accuracy requirements in most GSM networks when LMUs are deployed at only 50% of the cell sites.

Analysis of GSM UL-TDOA

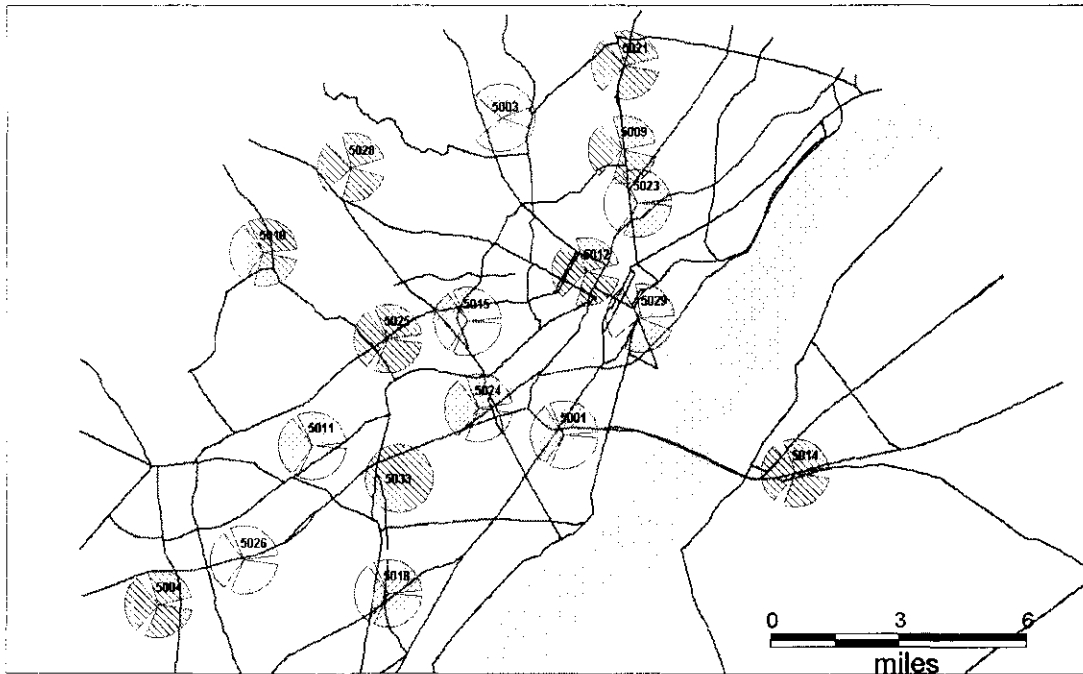
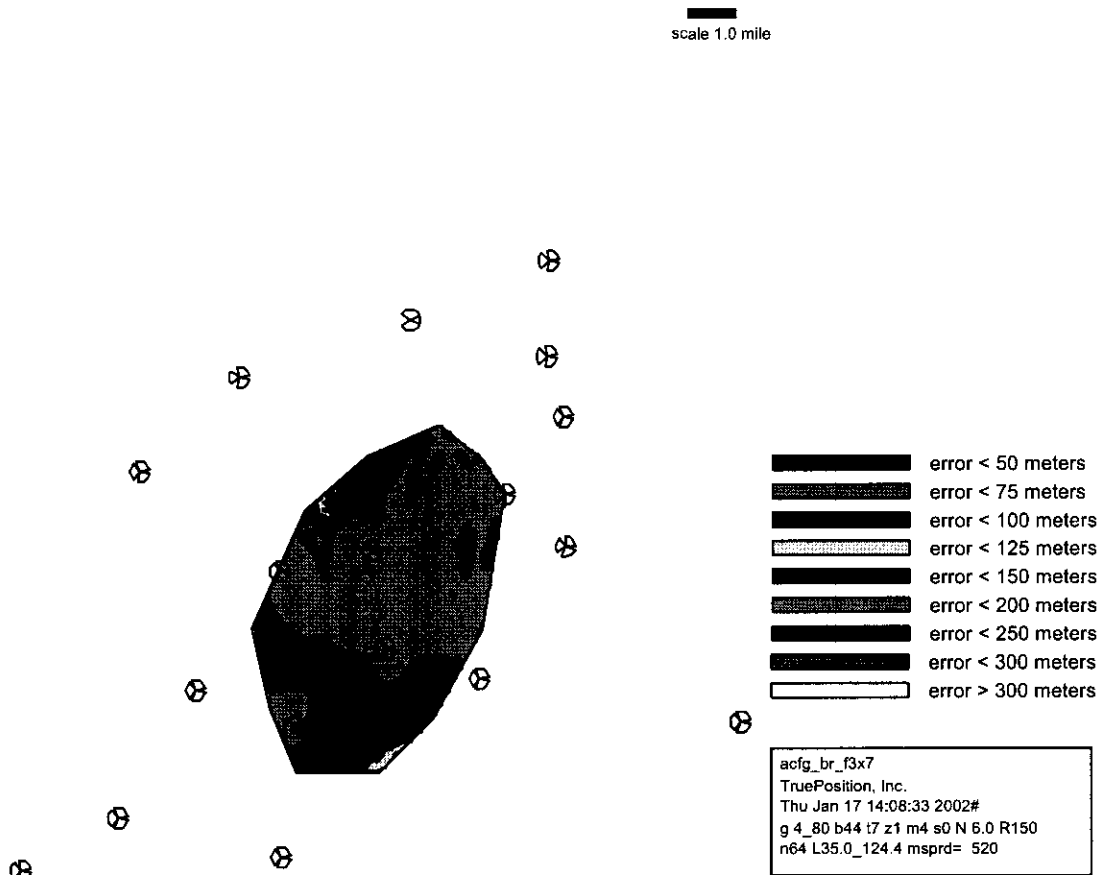


Figure 6 - Wilmington 850 MHz AMPS/TDMA Network

Analysis of GSM UL-TDOA

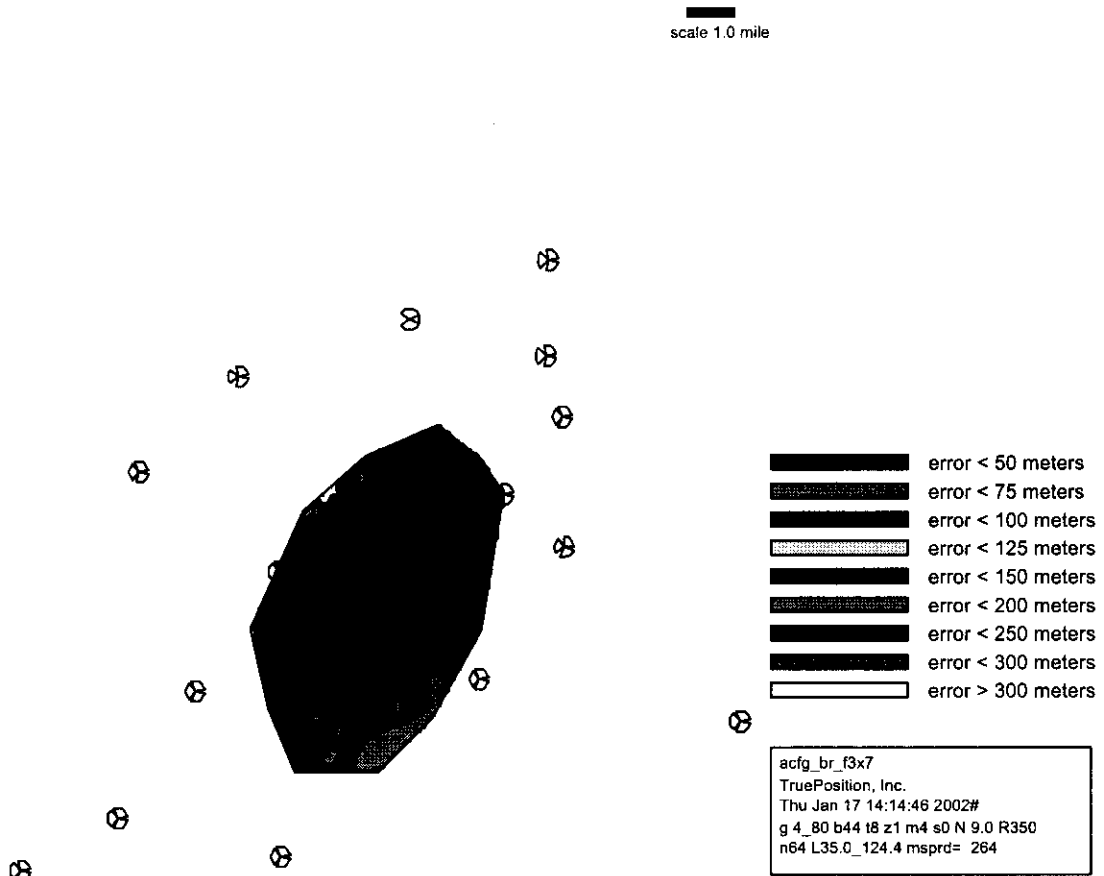


TruePositionTM

Sysid: 10018 overall rms= 77 p67= 80 p95= 135 meters

Figure 7 – Wilmington TDMA Performance

Analysis of GSM UL-TDOA

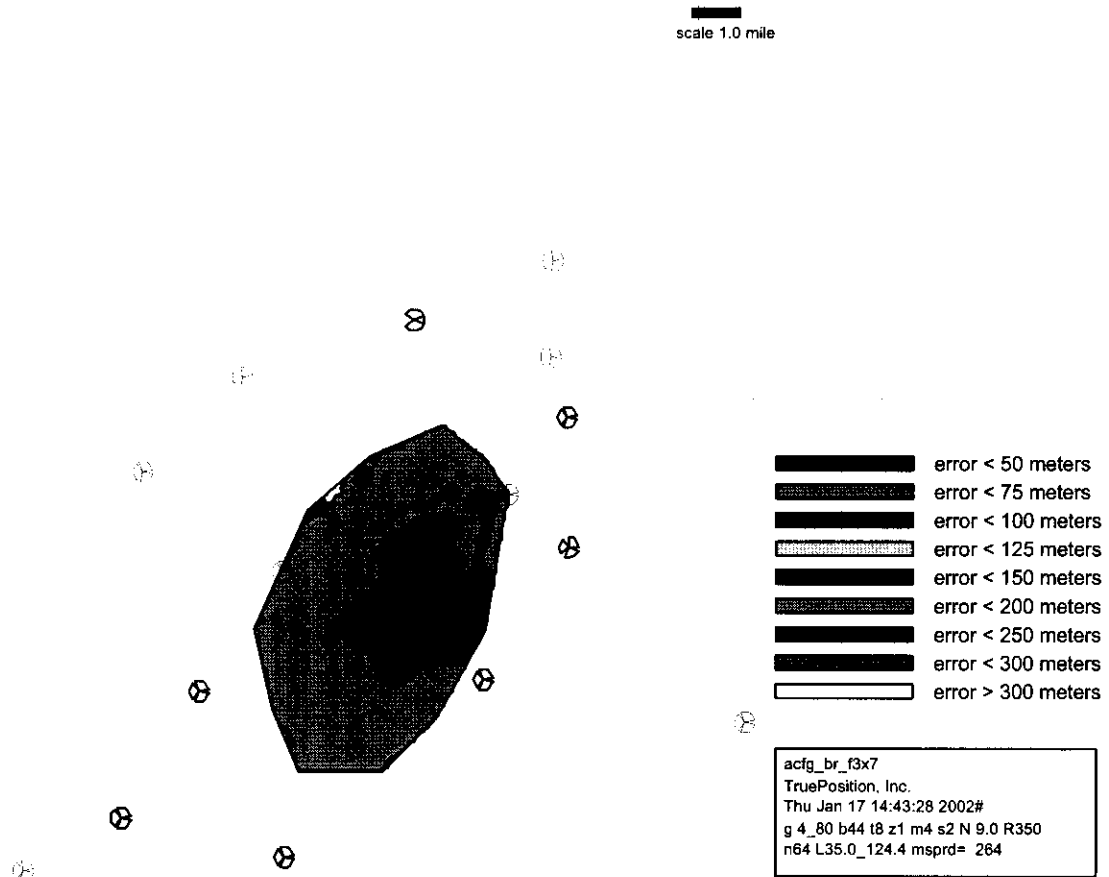


TruePosition[™]

Sysid: 10018 overall rms= 42 p67= 43 p95= 74 meters

Figure 8 - Wilmington GSM Performance (100% LMU Density)

Analysis of GSM UL-TDOA



TruePosition[™]

Sysid: 50018 overall rms= 56 p67= 58 p95= 101 meters

Figure 9 - Wilmington GSM Performance (50% LMU Density)

Analysis of GSM UL-TDOA

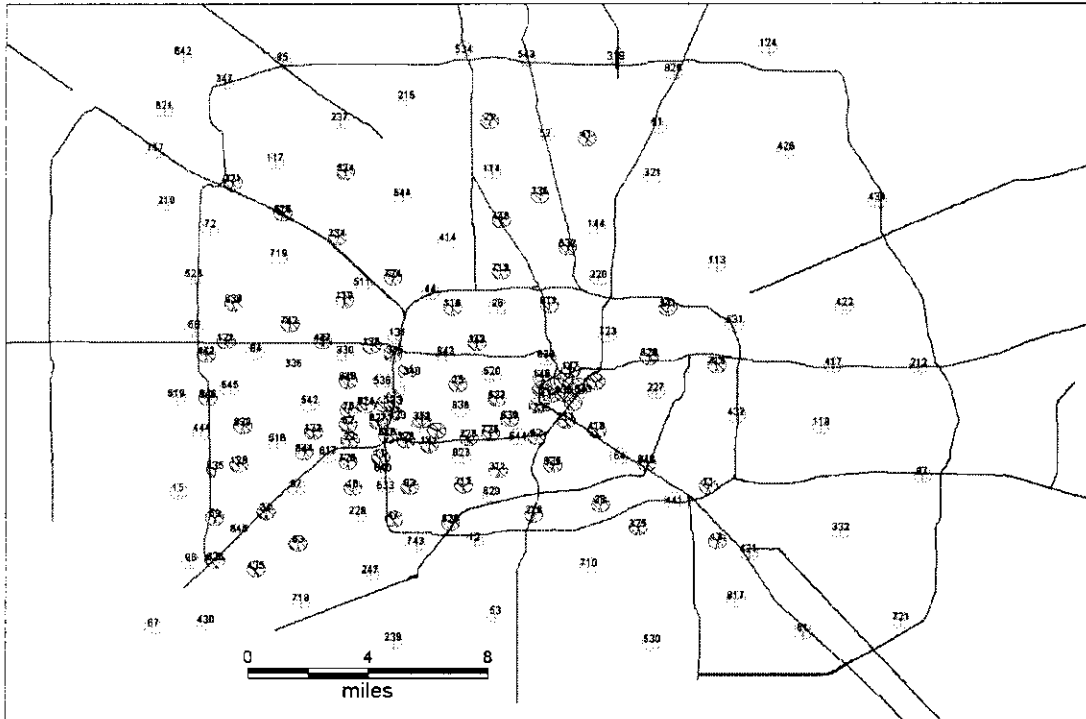
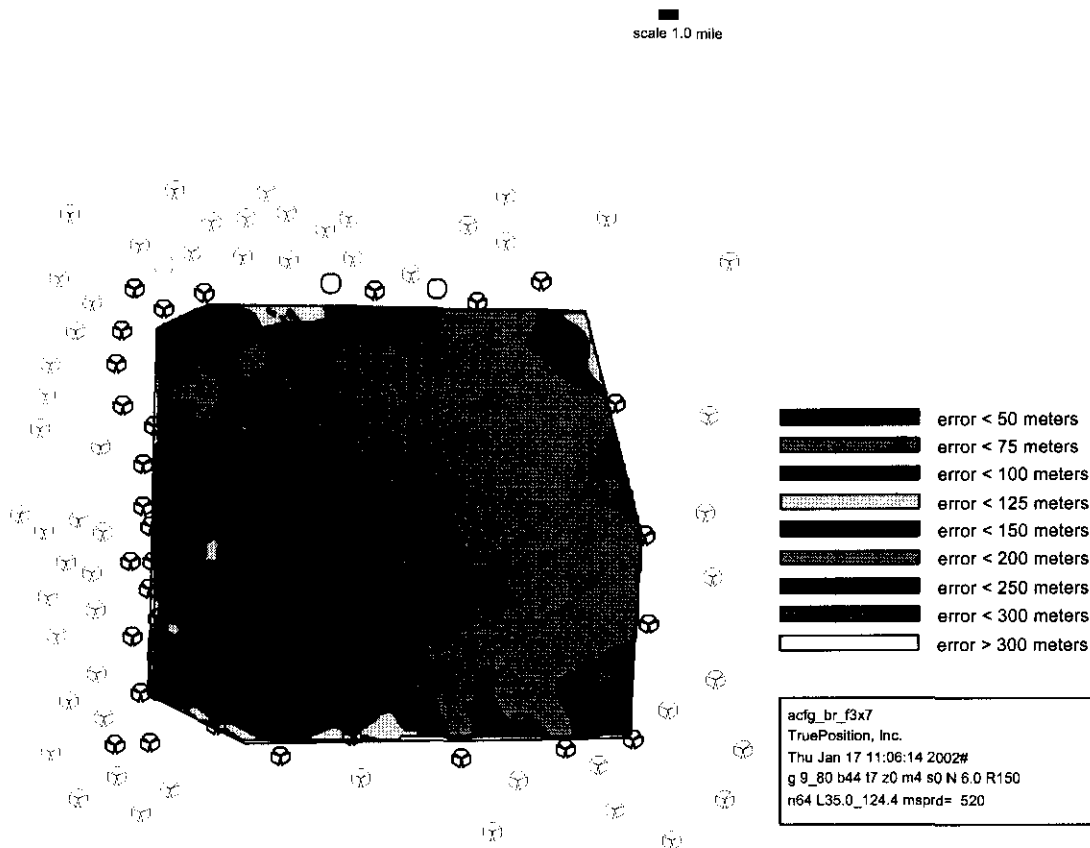


Figure 10 - Houston 850 MHz AMPS/TDMA Network

Analysis of GSM UL-TDOA

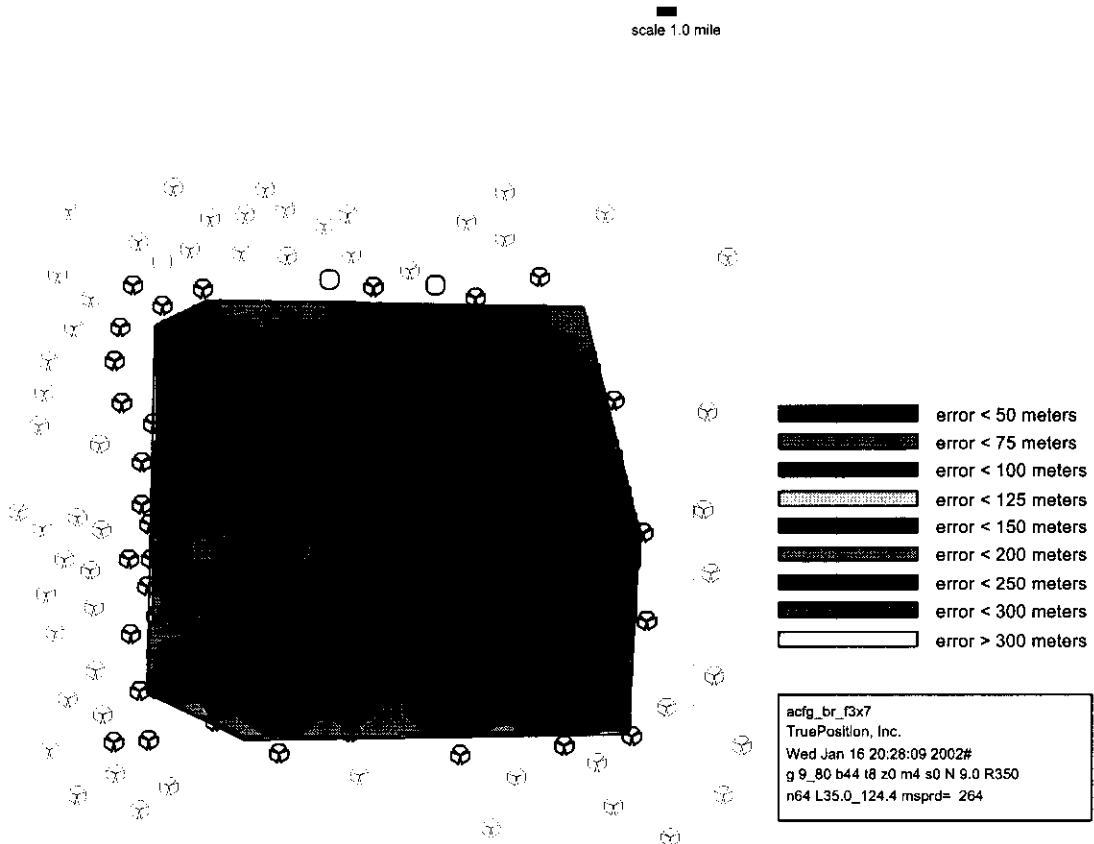


TruePosition[™]

Sysid: 10229 overall rms= 80 p67= 83 p95= 141 meters

Figure 11 - Houston TDMA Performance

Analysis of GSM UL-TDOA

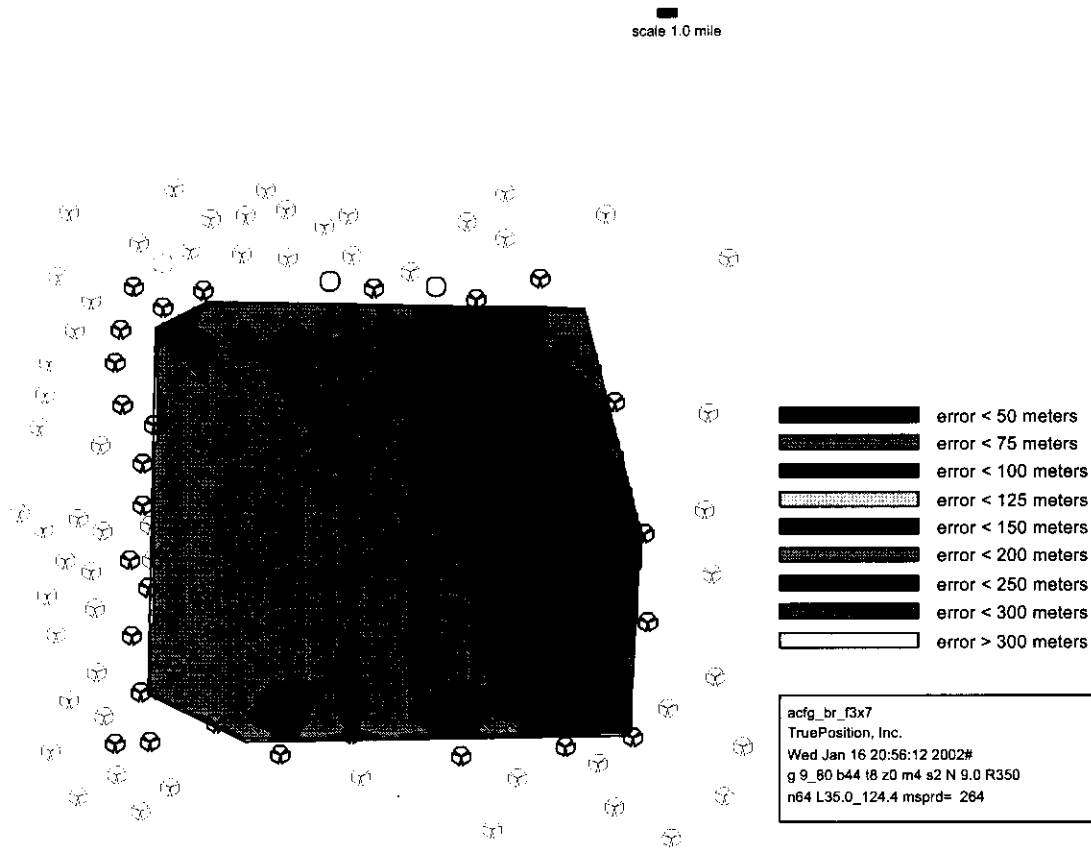


TruePosition[™]

Sysid: 10229 overall rms= 42 p67= 44 p95= 75 meters

Figure 12 - Houston GSM Performance (100% LMU Density)

Analysis of GSM UL-TDOA



TruePosition[™]

Sysid: 50229 overall rms= 50 p67= 52 p95= 89 meters

Figure 13 - Houston GSM Performance (50% LMU Density)

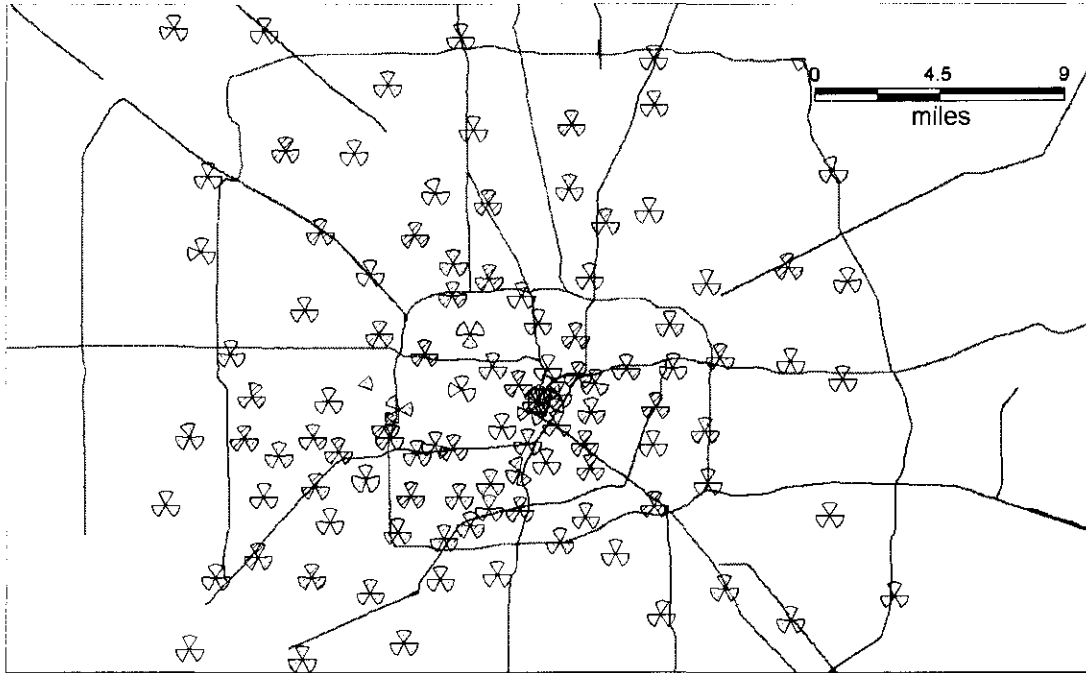
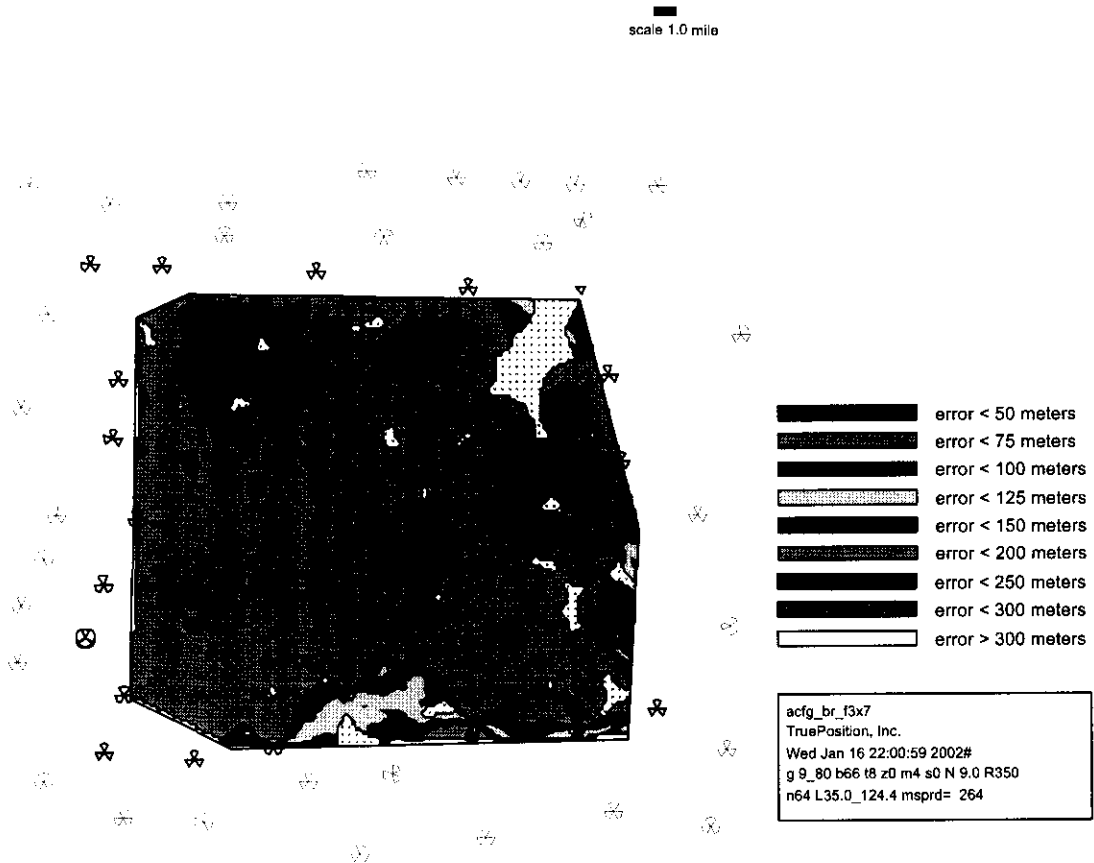


Figure 14 - Houston 1900 MHz GSM Network

Analysis of GSM UL-TDOA

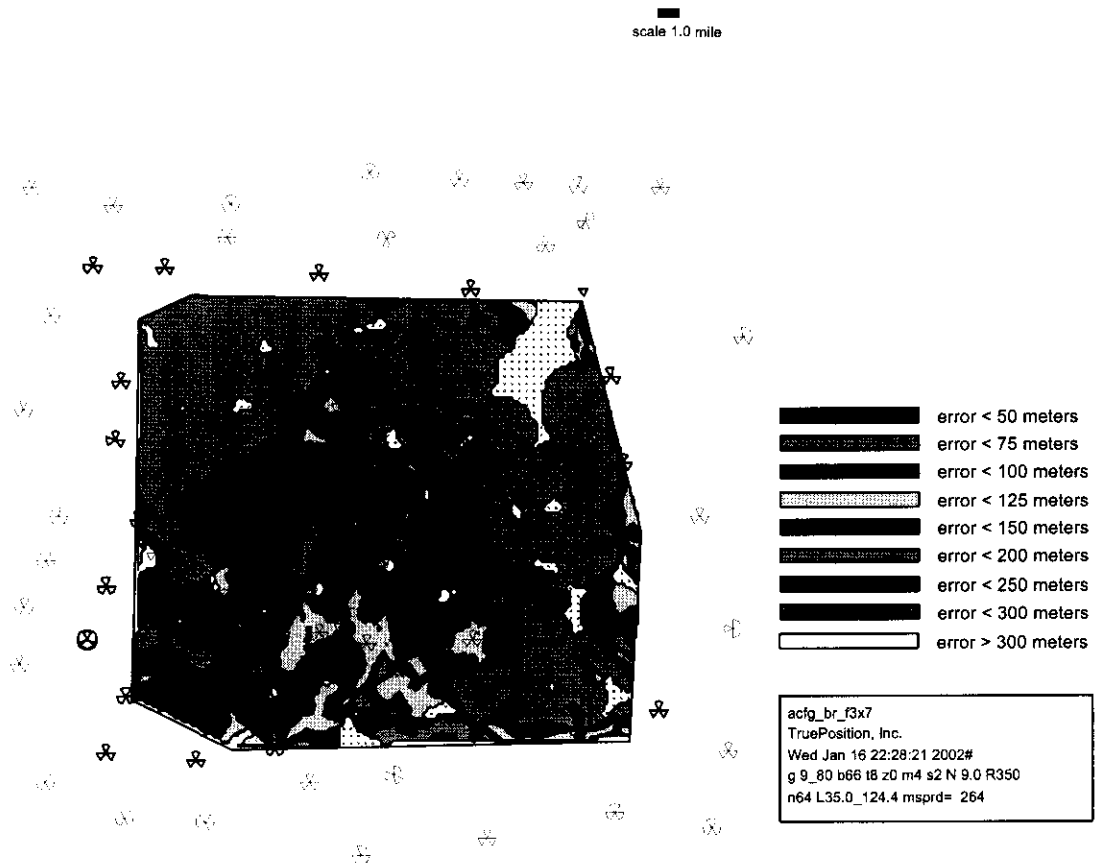


TruePosition[™]

Sysid: 10144 overall rms= 63 p67= 61 p95= 112 meters

Figure 15 - Houston 1900 MHz GSM Performance (100% LMU Density)

Analysis of GSM UL-TDOA



TruePosition[™]

Sysid: 50144 overall rms= 164 p67= 82 p95= 153 meters

Figure 16 - Houston 1900 MHz GSM Performance (50% LMU Density)

Conclusion

From a location accuracy perspective the significant difference between GSM and TDMA is signal bandwidth. The 5:1 difference in bandwidth makes GSM significantly more immune to multi-path than TDMA. A comprehensive analysis showed a 2:1 ratio of TDMA to GSM errors for the typical multi-path case, and nearly a 4:1 ratio for the severe case. Based on this analysis, TruePosition is confident that the RMS TDOA errors for GSM will be approximately half of those for TDMA. As a result, the accuracy of TDOA for GSM should be at least twice that of TDMA. In addition, the TruePosition WLS should be able to achieve the FCC's accuracy requirements in most GSM networks when LMUs are deployed at only 50% of the cell sites.

The UL-TDOA performance results presented in this analysis are conservative. They only take into account the increased signal bandwidth of GSM. They do not take into account frequency hopping on the uplink channels and the significant benefit this has in reducing multi-path. Also, they do not take into account more aggressive techniques for mitigating the effects of multi-path in a GSM environment that are currently being developed by TruePosition. These techniques for super-resolving multi-path and detecting leading edge components have potential to improve results even further. TruePosition is confident that the performance of UL-TDOA in actual deployments will be more accurate than the results presented in this analysis.